ink; forehead white, advancing over each eye to near its posterior angle; lores, a narrow line above the eyes, crown and nape black; upper surface of the body and wing-coverts grey; the first primary slaty black on the outer web and along the inner web next the shaft; the shaft itself and the outer half of the inner web white; the second primary similarly but a little less strongly marked; the remainder of the primaries silvery grey, with lighter shafts; throat and all the under surface of the body silky white; tail white; feet yellow.

Total length 10 inches; bill, from the gape, $1\frac{5}{8}$, wing $7\frac{1}{2}$, tail $4\frac{3}{8}$, tarsi $\frac{3}{4}$.

Hab. Torres Straits.

Remark. Two specimens of this bird are now before me:—one, a female, which has been in my collection for many years; the other, a fine adult male, forming part of the collection above mentioned, and which had lately been received at Adelaide from the northern territory at Port Darwin.

I have carefully compared this species with the *Sternula nereis* of Australia, the *S. minuta* of Europe, and the *Sternula* of India, supposed to be identical with the latter (but this, I think, is a question). I have also compared it with all the little Terns of America, both North and South. Its nearest ally seems to be the European species; but from this it differs in having considerably longer wings, in the snow-white hue of the shafts of the primaries, and in the larger and well-defined mark of black on the tips of the mandibles; from *S. nereis* it is distinguished by having black instead of white lores.

XXIII.—*Whence comes the Nourishment for the Animals of the Deep Seas?* By Prof. KARL MÖBIUS*.

THE investigations of the greatest depths of the ocean, made in Baffin's Bay by John Ross (1818), in the Pacific Ocean by James Ross (1843), in the North-Atlantic Ocean by Wallich (1860), near Spitzbergen by Chydenius and Torell (1861), in the north-eastern part of the Atlantic by Carpenter, Jeffreys, and Thomson (1868 and 1869), and in the Gulf-stream off Florida by Pourtales (1869), have shown that the bottom of the ocean at great depths (550–3000 fathoms) consists princi-

* Translated by W. S. Dallas, F.L.S., from a separate copy of the paper sent by the author to Dr. J. E. Gray, F.R.S.

pally of a *fine tenacious mud* (Schlick, mud, ooze) in which a great number of animals of various classes find all the conditions of their sustenance, and therefore also the nourishment necessary for their growth and for the production of their progeny.

The grave question as to the origin of this nourishment would no longer occupy the attention of biologists if living plants, containing chlorophyll, had been also brought up from these depths. But as these are wanting, G. C. Wallich ascribes to the Rhizopoda of the deep sea the faculty of separating from the surrounding medium the elementary constituents of their bodies. (North-Atlantic Sea-bed, 1862, pp. 130–132; and Intellectual Observer, Dec. 29, 1869.)

But, according to the present state of biology, only organisms containing chlorophyll possess the power of producing albuminoid compounds from carbonic acid, water, ammonia, and nitric acid. We must therefore for the present abstain from endowing *hypothetically* any kind of beings destitute of chlorophyll with this faculty, in order to explain the mode of nutrition of the animals of the deep sea.

Nor should we make any advance towards the true solution of the question before us if we were to suppose the protoplasmic being which Huxley has described (in the 'Quarterly Journal of Microscopical Science,' 1868, vol. viii. p. 201) under the name of *Bathybius Hæckelii*, and which Häckel has further elucidated (in the 'Jenaische Zeitschr. für Med. und Naturw.' 1870, vol. v. p. 492), to be produced by continual spontaneous generation at the bottom of the sea.

So long as such notions are destitute of *actual proof*, we must, in order to keep solid ground under our feet, seek the origin of the nourishment of the deep-sea animals in the upper regions of the sea, in which plants containing chlorophyll collect supplies of organic material.

This is done by the English investigators of the deep sea, W. Thomson, Carpenter, and Jeffreys. Carpenter is inclined to accept the hypothesis proposed by Thomson, according to which the Protozoa of the deep sea are nourished by protoplasm which is diffused through the whole mass of the sea-water, renewed constantly by the plants and animals living at its surface and penetrating by diffusion even to the greatest depths ('Nature,' March 31, 1870, pp. 564, 565).

In support of this view it is remarked that nitrogenous organic masses could be recognized by chemical reagents, not only in the higher strata, but even in those of a depth of 500–700 fathoms. The *microscopic* properties of *protoplasm* have not, however, as yet been demonstrated in these nitrogenous bodies; and so long as this has not been done we must refuse them this name.

Gwyn Jeffreys derives the decomposed organic mass at the bottom of the sea from animals which have sunk down from the surface ('Nature,' Dec. 9, 1869). Maury expresses himself similarly in his 'Physical Geography of the Sea' (edition 1869, § 617):—"The Ocean," he says, "swarms with living creatures, especially between and near the tropics. The remains of their myriads are carried on and collected by the currents, and in course of time deposited like snow-flakes on the bottom of the sea. This process, going on for centuries, has covered the depths of the ocean with a mantle of organisms as delicate as hoarfrost and as light as down in the air"*.

These statements of Maury's were so far confirmed by Wallich, that, in those places where few or no Foraminifera lived, he found a thin layer of an organic deposit, measuring from half an inch to an inch in thickness (North-Atlantic Sea-bed, p. 138).

All these attempts to explain the origin of the organic material at the sea-bottom leave unconsidered another way by which certainly great masses of organic and especially vegetable nutritive material are constantly reaching the sea-bottom.

In the first volume of the 'Fauna der Kieler Bucht,' Dr. H. A. Meyer and myself have divided the bottom of this small Baltic gulf into the regions of the sandy strand, the green *Zostera*, the dead and decaying *Zostera*, the red Algæ, and the black mud. The regions of the living and decaying plants occupy the narrow slopes which fall from both shores towards the depths. The black mud is a fine pasty mass which occupies the wide deeper part of the valley of the gulf in so thick a layer that it is not possible to penetrate it entirely with dredges. The surface of the mass of mud is an almost regular plain with a slight inclination towards the opening of the gulf; near the town it is 6 fathoms below the surface, and sinks gradually in a distance of two miles to a depth of 10 fathoms. All lines drawn upon this inclined plane from one side of the bay to the other are almost entirely straight. This flatness of the bottom is caused by the constant descent of sinking materials from the slopes on each side. In this way the deep sea-bottom receives annually a fresh supply of organic matters. The plants which have grown in the higher

[* This source of the nutriment of deep-sea animals was indicated as the most probable one by the Translator, in a notice of Dr. Wallich's 'North-Atlantic Sea-bed,' Ann. & Mag. Nat. Hist. 1862, ser. 3. vol. x. p. 383.]

regions sink to the bottom after they have died, gradually break up into smaller and smaller portions, and finally glide down into the greatest depth that they can attain. The same course is taken, as I know from personal observation, by the vegetation in the bay of Heligoland, at those places where no strong currents of ebb and flow prevent the deposition of organic masses.

This organic and chiefly vegetable mass, in the particles of which we may often still recognize cellular structure and demonstrate the presence of cellulose by iodine and sulphuric acid, is what renders the mud-region inhabitable by a great number of animals—in the first place, by those which feed upon decaying matters, and then for others which devour the dirt-eaters. In this way we find it easy to explain the quantities of individuals, at the first glance quite astonishing, which may be got out of the mud of the greater depths; for the mass which serves them as a dwelling-place at the same time contains an enormous store of nourishment for them.

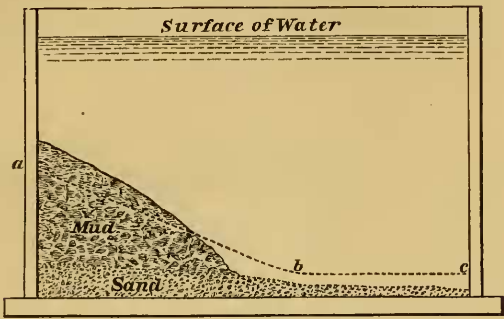
The same thing must take place in all seas. In the shallower regions which immediately surround continents and islands, great masses of Algæ grow wherever there are rocks and stones. In the warmer seas there is an enormous floating Sargasso-life. Only a small portion of these plants is directly eaten by animals or thrown upon the shore. Most of them die where they have lived, or, after they have been carried away by currents and winds, lose the gases which make them lighter than sea-water, sink down, and finally become decomposed into a soft mass. In such a state as this Wallich found considerable quantities of dead plants, in depths which extended beyond 500 fathoms (North-Atlantic Sea-bed, p. 130).

With the sinking organic materials are, of course, intermixed the remains of Testacea and the fine inorganic soil-constituents of the higher regions, which the currents of flood and ebb and the waves are unceasingly triturating. This muddy mixture must move down towards the deeps upon the sloping sea-bottom in the neighbourhood of the coasts, from purely mechanical causes, until the weight and mutual adhesion of the individual particles present so much resistance to the pressure of the masses following them from above that equilibrium is produced.

For the purpose of accurately testing the causes by which sinking materials are moved down in a water-basin from the higher to the lower regions, I made some experiments with two rectangular aquaria. The space for water in the smaller one (fig. 1) was 15 centims. long, 10 centims. broad, and

6 centims. high; that of the larger one (fig. 2) 53 centims. long, 28 centims. broad, and 16 centims. high. The two larger perpendicular walls were glass plates*.

Fig. 1.



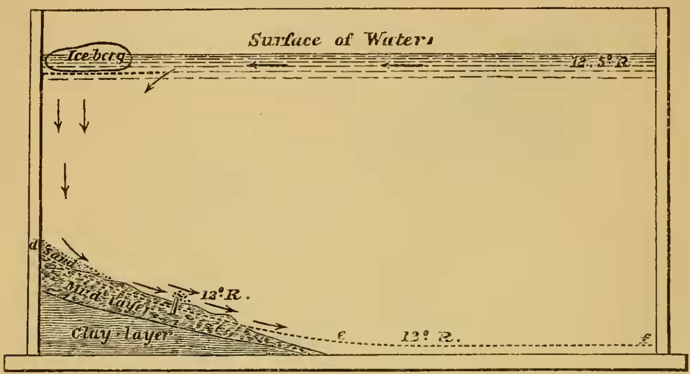
The bottom of the smaller aquarium, after it had been filled with water, was covered with a thin layer of sand, to which I gave an inclination of about 5° (fig. 1). I then, by means of a spoon, allowed fine mud-particles, which had been sifted out of the mud of the mud-region of the harbour of Kiel, to sink slowly down upon one of the narrower sides of the aquarium, until a slope of 35–40° had been formed. The heaped-up mass was inhabited by a number of small animals. *Gammarus locusta*, *Cuma Rathkii*, *Jæra albifrons*, *Scoloplos armiger*, *Nemertes gesserensis*, *Monocelis agilis*, *Pontolimax capitatus*, *Corbula gibba*, *Tellina balthica*, and *Scrobicularia alba* soon made themselves visible in the superficial layer. The next day the mass had settled a little, and its lower boundary had already perceptibly advanced. On the third day its progress was already 3 centims. I now laid a few spoonfuls of sand upon the uppermost part of the slope, and then disturbed the equilibrium of the water for a few minutes by moving a finger up and down in it. By this means the abruptly rising sand acquired a more oblique direction, and covered the mass of mud for a breadth of several centimetres. Two days later, this sand had for the most part sunk down into the mass of mud and pushed it still further forward even at the bottom. Its angle of inclination had decreased from 35–40° (its original amount) to 25°, and the sand spread over the horizontal bottom was covered throughout with fine mud-particles (fig. 1, line *a*, *b*, *c*).

* The two figures represent profiles of these aquaria. The dotted line indicates the future surface of the organic mass. In fig. 2 the arrows indicate the direction of the sinking current.

Before discussing the causes of these changes, I will describe the experiments made with the other and larger aquarium.

Two fifths of the surface of the bottom of this aquarium were covered with a layer of clay, which was laid against one of the narrower walls, and fell with a slope of 12–15° towards the horizontal part of the bottom (fig. 2). The lower boundary

Fig. 2.



of this clay-slope was not rectilinear, but curved inwards in the middle. Round this sinuosity the slope was a little more inclined than near the glass walls of the aquarium. It was then filled with sea-water. After this had become quite clear, the bottom was covered with a very thin coat of clay.

The inclined layer of clay was now carefully covered with unsifted mud from the harbour, inhabited by animals. It formed a slope with an inclination of about 20°. The surface had irregular elevations and depressions, and at its lower margin a reentering curve.

On the following day the surface had become nearly smooth. Living bivalves and worms projected from it and performed their movements. *Scrobicularia alba*, *S. piperata*, and *Tellina balthica* stretched their two mantle-tubes far out of the shell, felt about with the inferior one upon the surface, stirred it up and drew in particles from it; sometimes a stream of fæcal masses passed out of the upper tube and sank down. Here and there a tube of *Pectinaria auricoma* projected from the mud, and from this also fine mud-masses were sometimes expelled. *Leucodore ciliata* waved its filiform tentacles to and fro before its tube. *Edwardsia duodecimcirrata* spread out its circle of tentacles upon the surface of the mud. *Nassa reticu-*

lata, *Hydrobia ulvæ*, *Jæra albifrons*, and *Polynoë cirrosa* crept about upon it upwards and downwards or buried themselves in the soft mass.

Third day. A mixture of sand and finely comminuted shells from the harbour was laid upon the highest part of the slope. This addition formed a wedge of 6 centims. length, with an inclination of 25–26°.

On the *fourth*, *fifth*, and *sixth days* the water was set in motion for a few minutes, at the surface, by means of a glass rod.

On the *seventh day* the greater part of the comminuted shells and sand had sunk in.

On the *ninth day* scarcely any thing but organic mass was to be seen at the surface. The angle of inclination of the slope had sunk from 26° to 20°. The reentering curve at its lower end was almost entirely filled up, and the horizontal part of the bottom covered with mud-particles to a thickness of from 1 to 2 millims.

Tenth day. The temperature of the water was 12·5° R. (=60° F.). Over the highest part of the heap of soil (close to the shore) a wire framework was suspended at a depth of 15 millims. below the surface of the water; and upon this was laid an india-rubber bag filled with ice, for the purpose of cooling the superficial water (fig. 2). Immediately there was produced a movement of the water passing downwards upon the slope. If a *Tellina*, a *Scrobicularia*, or a *Pectinaria* threw out mud, this was carried downwards with some velocity from 10 to 15 millims.; when the Mollusca and worms creeping about stirred up particles of the surface, the current carried these along with it. At the surface a movement of the water towards the cooled spot took place, floating corpuscles went with this, sank down, and glided downwards over the inclined bottom. These movements continued until all the ice was melted, although during this period the difference between the superficial and bottom strata of water amounted only to ½° R. (=1°·125 F.).

On the *thirteenth day* the surface was cooled a second time in the vicinity of the shore.

On the *sixteenth day* the lower boundary of the slope had advanced in one place 10 millims., in another 20 millims.; its inward curve was entirely filled up; its angle of inclination amounted to 17° above and only to 15° below. On the horizontal bottom the fine organic mass lay to a thickness of 3 or 4 millims. This diffusion of the organic mass was followed by worms and Mollusca; and Infusoria swarmed at the bottom.

The aquarium was now left entirely to itself. At the end of four weeks the lower boundary of the slope had nevertheless advanced about 2 centims. further, and the horizontal part of the bottom was covered with mud-particles still more thickly than before.

In both aquaria, therefore, mechanical, thermic, and living forces cooperated to bring about a forward movement of organic materials from the higher towards the lower regions.

Sand-grains and fragments of shells, when laid on the top, pressed the organic mud-particles aside by sinking in between them. As gravity resists their ascent towards the shore, the mass must on the whole go further downwards.

When the bottom is heated in the higher regions, the volume of the constituents of its soil increases. In consequence of this extension, the mass must move more downwards than upwards, because gravity here also opposes movement upwards.

If a cooling of the water takes place above the shallower regions, it becomes condensed, sinks down, and runs upon the sloping ground down into the deeps, where there is warmer and lighter water, which it displaces and replaces. The bottom current carries light organic bodies with it into the deeps.

Fluctuations in the equilibrium of the water, and the restlessness of animals which live on the bottom, both in the higher and lower regions, their creeping about, tube-building, seeking of nourishment, expulsion of indigestible materials, respiration, and growth, keep the constituents of the superficial layer of soil loose and in constant movement, so that they can readily be carried away by the water flowing downwards.

The same moving forces operate also in the sea. Here not only is the extension of the water-basin infinitely greater, but even the sum of the forces is enormously increased.

Dead plants, fragments of shells, and sand are heaped one upon the other to a height of feet or fathoms. The alternation of flood and ebb and the winds keep the upper strata of the water in constant movement, and produce oscillations up and down, even in the lower ones, by increasing or diminishing the column of water resting upon the bottom. The differences of temperature which are dependent on the alternation of day and night, on changes of weather and the course of the seasons, cause expansions and displacements of the constituents of the bottom. Into the greater depths, where these forces can operate but rarely and slightly, or even not at all, the currents of sinking water, which has become heavier than the subjacent strata by cooling or increase of its amount of salt, penetrate.

In my aquarium a downward current, which readily carried organic bodies along with it, was produced when the difference between the superficial and bottom temperatures had scarcely attained half a degree (R.). In the seas of high latitudes, in autumn and winter, differences of temperature between the upper and lower strata of the water will certainly occur, sufficiently great to cause descending currents.

In the year 1869 I was enabled by the captain of the pilot schooner stationed at the mouth of the Ems near the island of Borkum to make some measurements of temperature there, which I may adduce as evidence of the correctness of this assertion. On the 10th September 1869, all the strata of water there (to a depth of 13 fathoms) had acquired a temperature of 13° R. ($=61\frac{1}{4}$° F.). From the 13th September this began to sink, and in the following manner: almost on each consecutive day the superficial stratum was about half a degree (R.) colder than the bottom stratum, until on the 25th December a temperature of only 1° R. ($=34\frac{1}{4}$° F.) was found at a depth of 7 fathoms, and at the surface only $\frac{1}{2}$° ($=33\frac{1}{8}$° F.). When sea-water begins to freeze, its refrigeration has descended to -2° R. ($=27\frac{1}{2}$° F.). This low temperature was observed in all strata of water in the North Sea at the north-eastern point of Sylt, on the 14th of February 1870*.

When the temperature of sea-water diminishes, its density increases. Therefore about the middle of September, a descending current must have been produced in the mouth of the Ems, and continued until all the strata had acquired an equally low temperature. There can be no doubt that in all seas of high latitudes, with a great alteration of temperature in autumn and winter, such descending currents move down from the shore-regions towards the deeps. In the North-Atlantic Ocean they must occur both on the European and North-American coasts far to the south. This appears from the summaries and charts lately published by A. Petermann on the Gulf-stream and the state of thermometrical knowledge of the Atlantic Ocean and land-district in the year

* In connexion with this I may call attention to a distinction between fresh and salt water which is frequently overlooked. Ordinary sea-water (containing from 3·2 to 3·4 per cent. of salts) only attains its greatest density when it is cooled below its freezing point (—2° R.). On becoming colder, therefore, it sinks until it meets with a stratum of water of its own density, or until it reaches the bottom. If it freezes on the way, the fresh water separated as ice rises to the surface, and the sea-water, which has become richer in salts, and therefore heavier, continues to sink.

1870*. From this I only extract, by way of example, the following:—

The temperature of the surface of the sea is:—

	in January.	in July.
On the Norwegian coast between Tromsö and Drontheim	1°·1–1°·5 R.	8°·2–9° R.
Near Bergen	4·3 R.	9·2 R.
On the west coast of Scotland	5·3 R.	10 R.
On the west coast of Iceland	0 R.	8 R.
On the east coast of North America, near Boston	0 R.	12 R.

In the temperature-measurements of the 'Porcupine' Expedition carried out in the summer of 1869 under the superintendence of the English investigators Carpenter, Jeffreys, and Thomson, the surface was found to be much warmer than the deeper strata of the water, as shown by the following numbers, which I select from a table furnished by Thomson (Petermann, *l. c.* p. 235):—

	Temperature of the surface in July.	Temp. of the surface in January, according to Petermann's chart.	Temperature of the depths in July.	Depth in Fathoms.
Atlantic ocean, west of Scotland	11°·1 R.	7° R.	2°·3 R.	1263
	11°·0 R.		2°·1 R.	1264
	10°·6 R.		2°·2 R.	1380
Between the Shetland and Faroe Islands	8°·9 R.	4–6° R.	0°·9 R.	345
Atlantic Ocean, in the west of the Bay of Biscay, 47° 38′ N. lat.	14°·9 R.	9° R.	2° R.	2435

In regions of the sea where the uppermost stratum of water, even on the coldest days, does not acquire so low a temperature as the deepest strata constantly maintain, in consequence of inferior currents from colder seas, descending currents must likewise pass down from the shore-regions towards the deeps, and persist until the progressive cooling of the surface ceases. In this case, indeed, the descending water itself will not attain the bottom lying beneath it; but the organic masses which it carried down from higher regions are there seized upon by still deeper cold currents, with which the last and finest remains of them finally get into the greatest depths, and there remain as the materials of mud (Schlick, ooze).

* Mittheilungen aus Perthes' Geogr. Anst. Bd. xvi. Heft 6 & 7.

Of all the movements which convey organic materials to the sea-bottom, descending currents are evidently among the most efficacious. Their operation falls precisely in the most suitable season for this purpose: it commences after the annual development of the marine vegetation in the temperate and cold zones has attained its maximum, when strong and long-continued storms gather their chief harvest in the fields of *Zostera* and tangle, and the bottom of the sea is disquieted to a greater depth than usual.

I am well aware that between a small bay like the harbour of Kiel and an ocean such as the Atlantic there is a great difference of space. But, as we know, by persistent operations Nature can bring the same things to pass in great spaces which are completed by her in smaller ones in less time. The slowness with which plants decay under water is very favourable to their long transportation before complete decomposition.

Wherever animals were found in great depths, the bottom was muddy. It is worth inquiry whether on elevations (on which little or no mud can remain lying, because the bottom-currents, being contracted there, must sweep the bottom more strongly) the population is not also feebler than in the deep valleys which abound in mud. In the bay of Heligoland those parts of the sea-bottom where the strong current allows neither living plants to grow nor dead ones to rest are very poor in animals.

According to all that we know about the distribution of animals on land and in the shallower parts of the sea, we must assume that the distribution of the deep-sea animals also is chiefly dependent on the presence of vegetable substances. And as yet we have only become acquainted with deep-sea animals which belong to classes living also in higher regions, and which consequently will partake of the same essential conditions of life with these.

To suppose that the simplest organisms originate at the bottom of the sea by primitive generation (*generatio primaria*) has something very seductive about it. It suits wonderfully well with old cosmogonies and new theories. But we shall never succeed in *demonstrating* its occurrence there. And even if we could methodically produce primitive generation in our laboratories, we could assert nothing further than that perhaps such primitive generation may take place also at the bottom of the sea.